The Pleistocene Ice Ages

EES 3310/5310

Global Climate Change

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Oxygen & Hydrogen Isotopes

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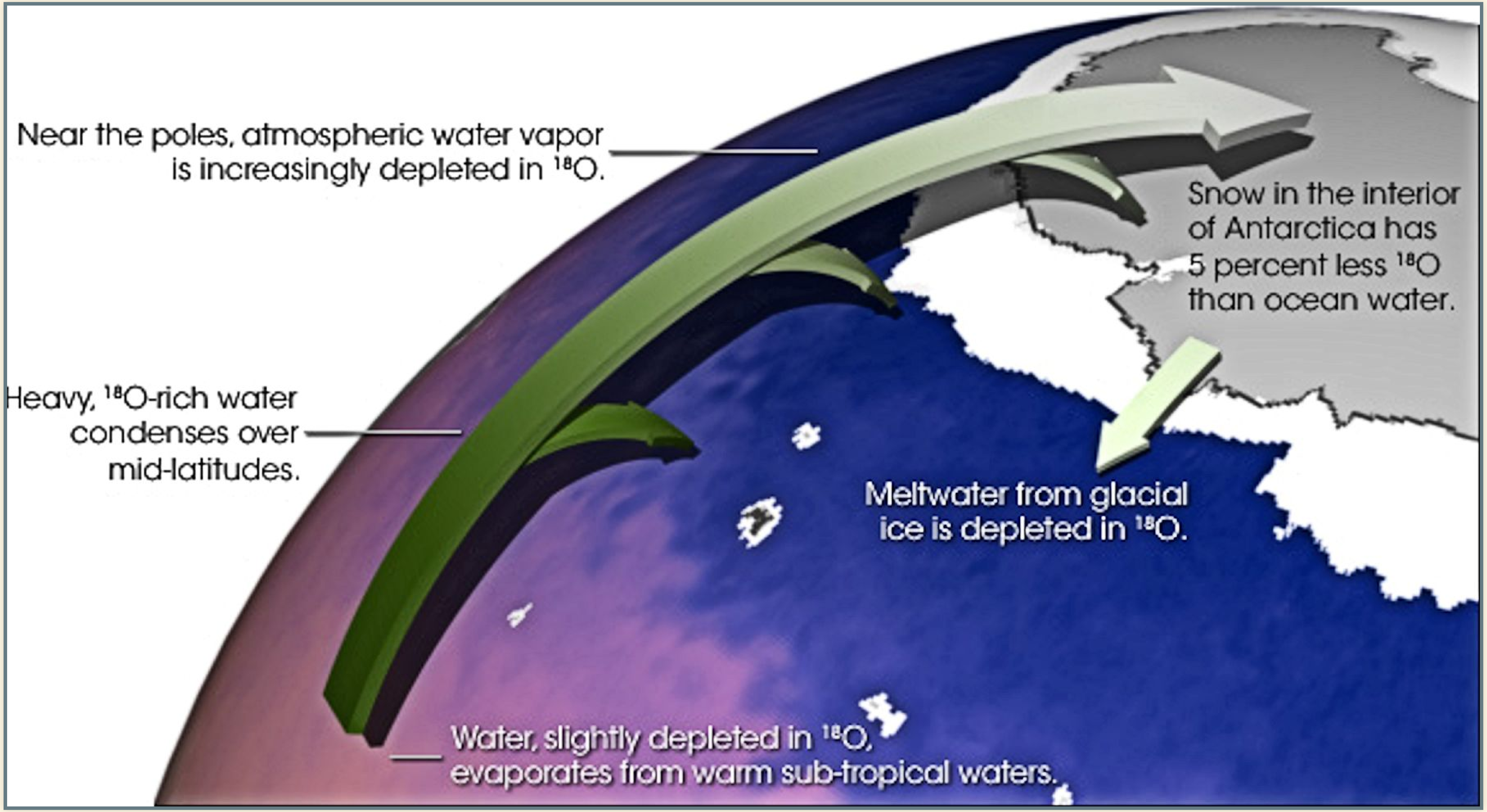
$$\delta^{18}\mathrm{O} = \left(\frac{\left(\frac{^{18}\mathrm{O}}{^{16}\mathrm{O}}\right)_{\mathrm{sample}} - \left(\frac{^{18}\mathrm{O}}{^{16}\mathrm{O}}\right)_{\mathrm{ref}}}{\left(\frac{^{18}\mathrm{O}}{^{16}\mathrm{O}}\right)_{\mathrm{ref}}} \right) \times 1000‰$$

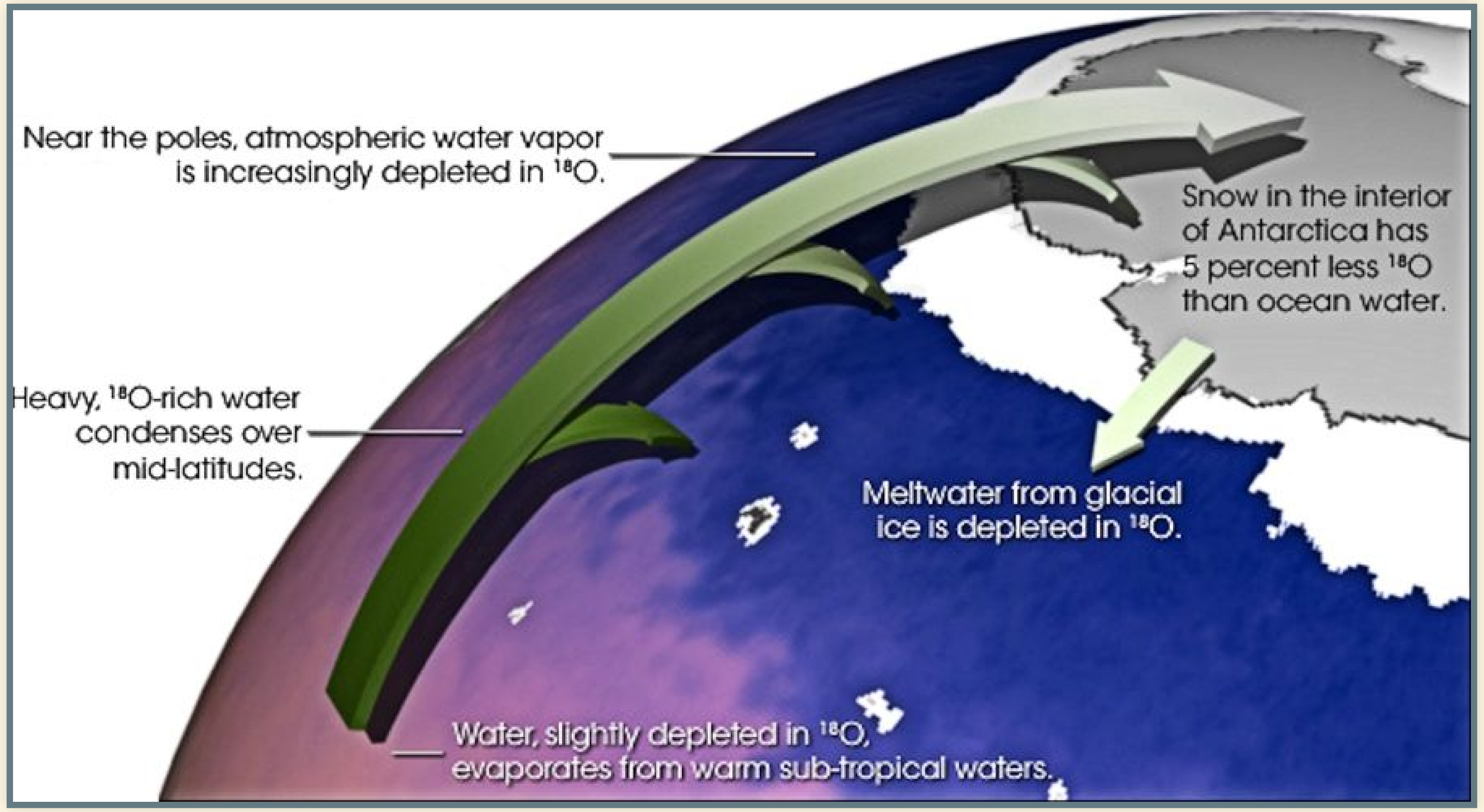
- Lighter isotopes (^{1}H and ^{16}O) evaporate faster
  - Vapor has less of heavier isotopes (lower δ^{18}O, δD)
  - Ocean is richer in heavier isotopes (higher δ^{18}O, δD)
  - Warmer $\rightarrow$ greater δ^{18}O, δD in vapor

Rain, Snow, Ice

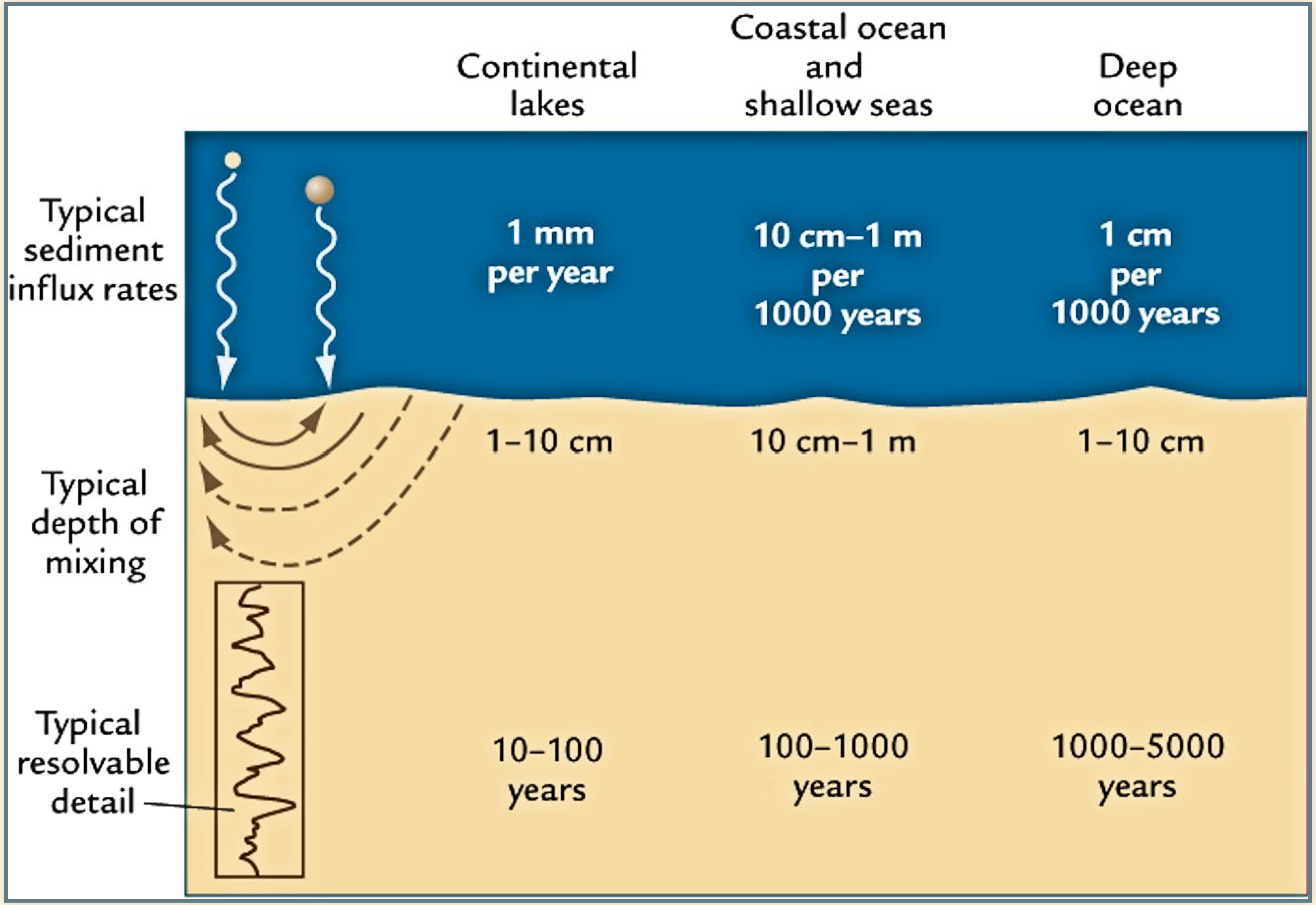


Rain, Snow, Ice

- Rain, snow are richer in heavier isotopes
  - More precipitation $\rightarrow$ less deuterium and ^{18}O left in vapor
  - Farther from source region $\rightarrow$ smaller δD and δ^{18}O.
- Reduction in δD and δ^{18}O depends on air temperature.
  - Different for H and O.
- Comparing δD and δ^{18}O can tell us about both sea-surface temperature and air temperature over glaciers.
- **Higher air temperature over glacier $\rightarrow$ higher δD and δ^{18}O in glacier snow/ice.**

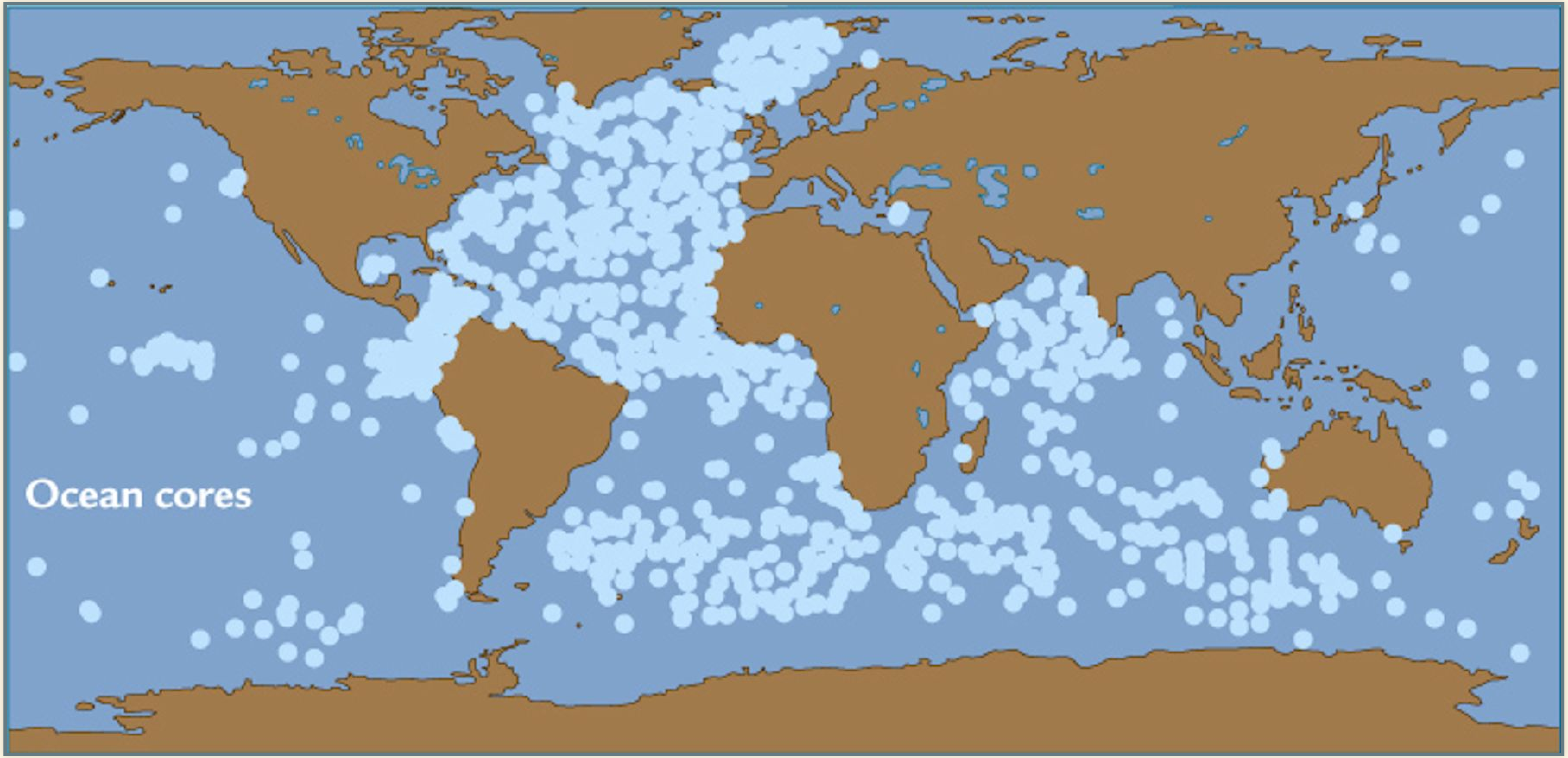


Sediments and History

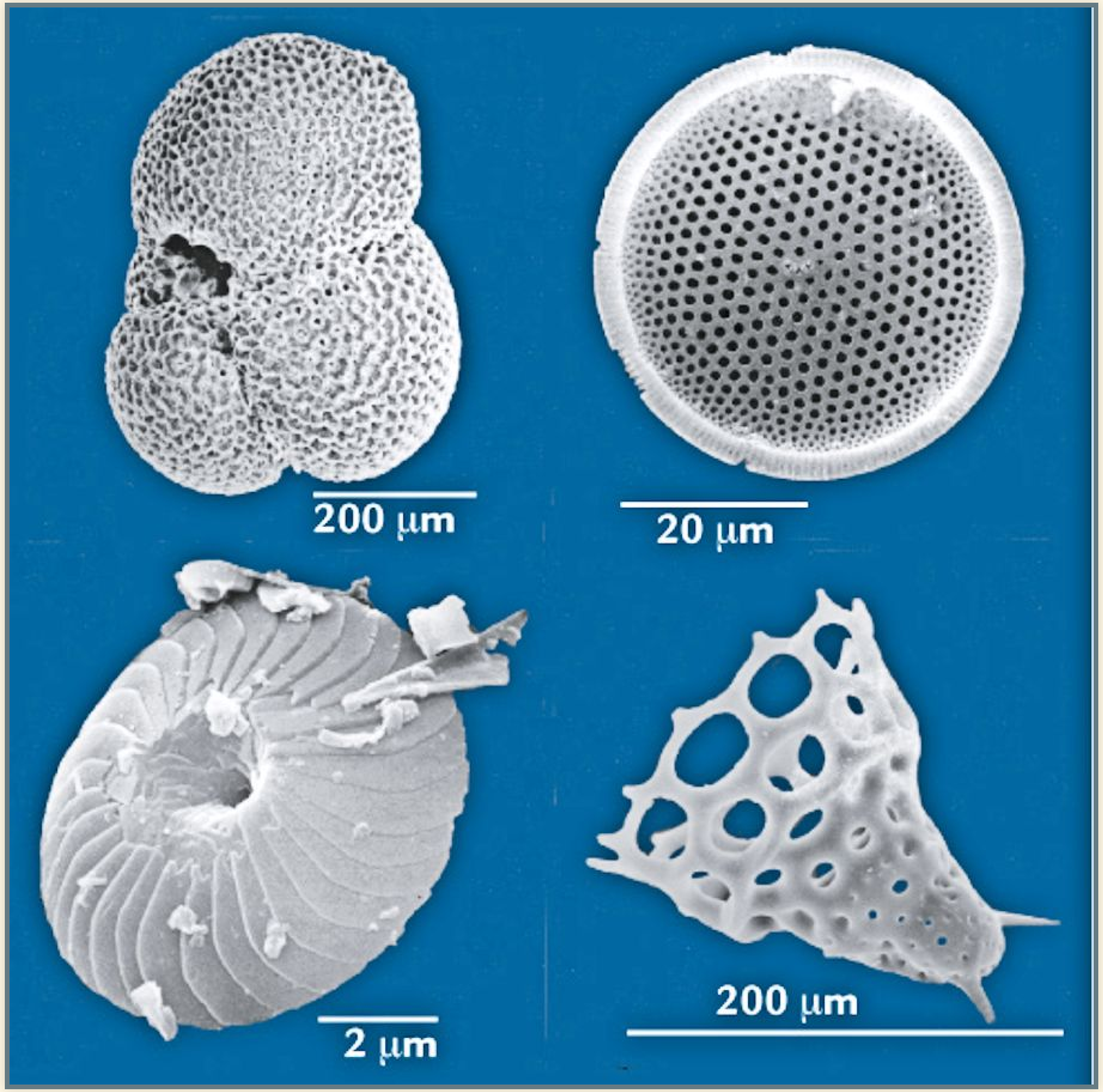


Bottom $\rightarrow$ top = oldest $\rightarrow$ youngest


Solving the Ice-Age Puzzle

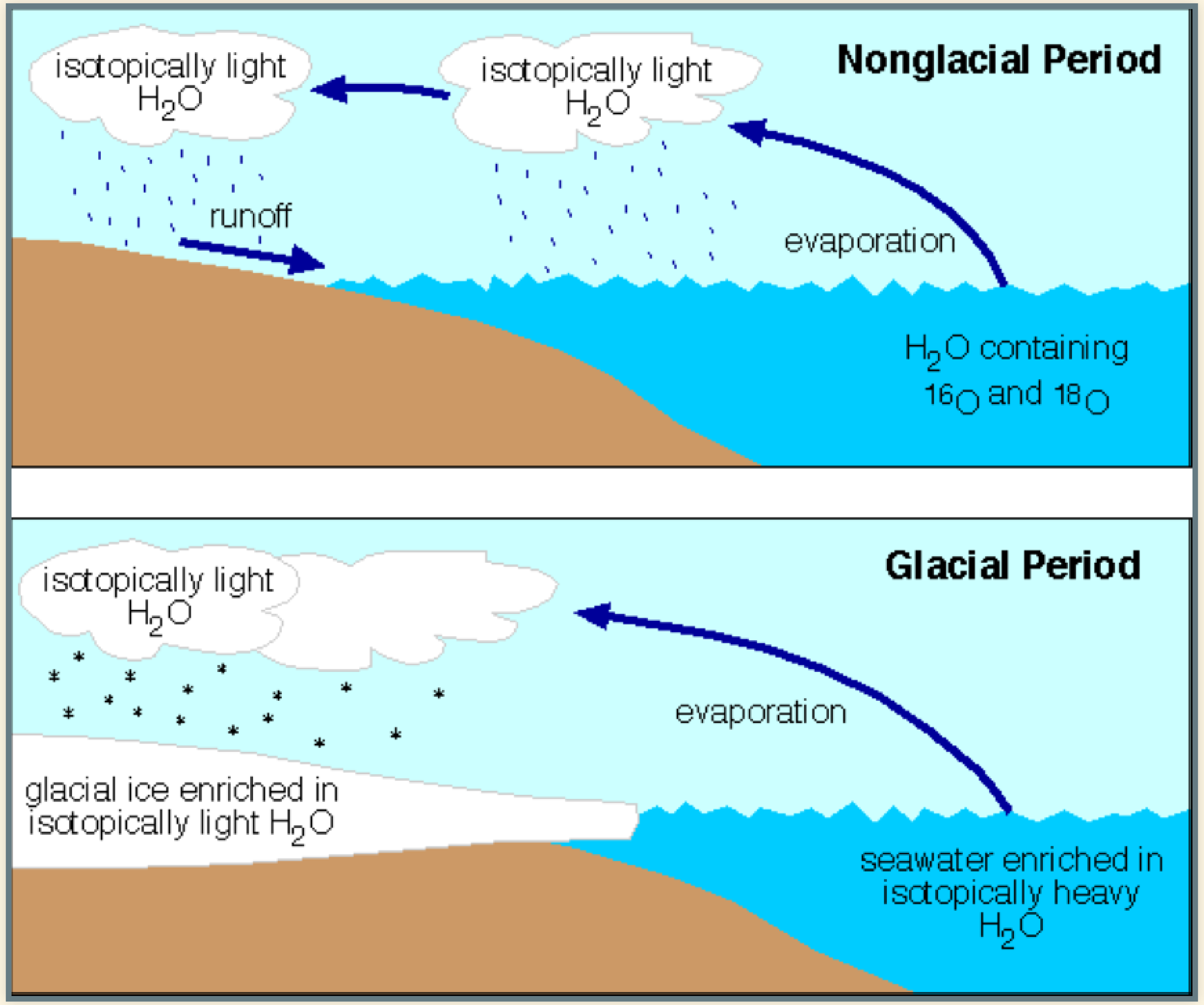


Deep-Sea Sediments

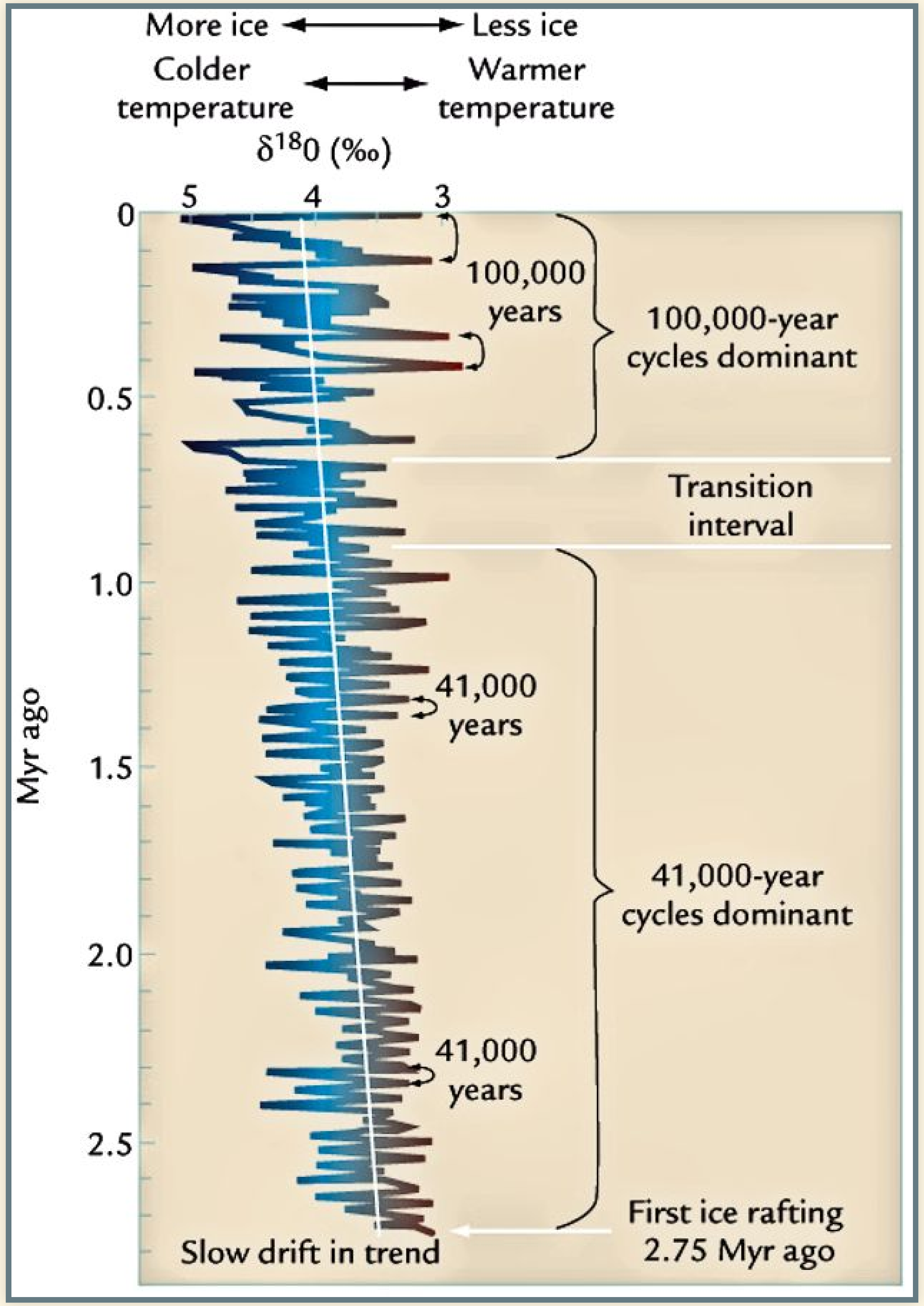


Past Sea Levels

- Water vapor, rain, snow is always isotopically lighter than sea water
- Snow, ice on land remove light isotopes from ocean
- Bigger glaciers:
  - Lower sea-level
  - Greater (positive) δ^{18}O in ocean sediments
- Smaller glaciers:
  - Higher sea-level
  - Smaller δ^{18}O in ocean sediments



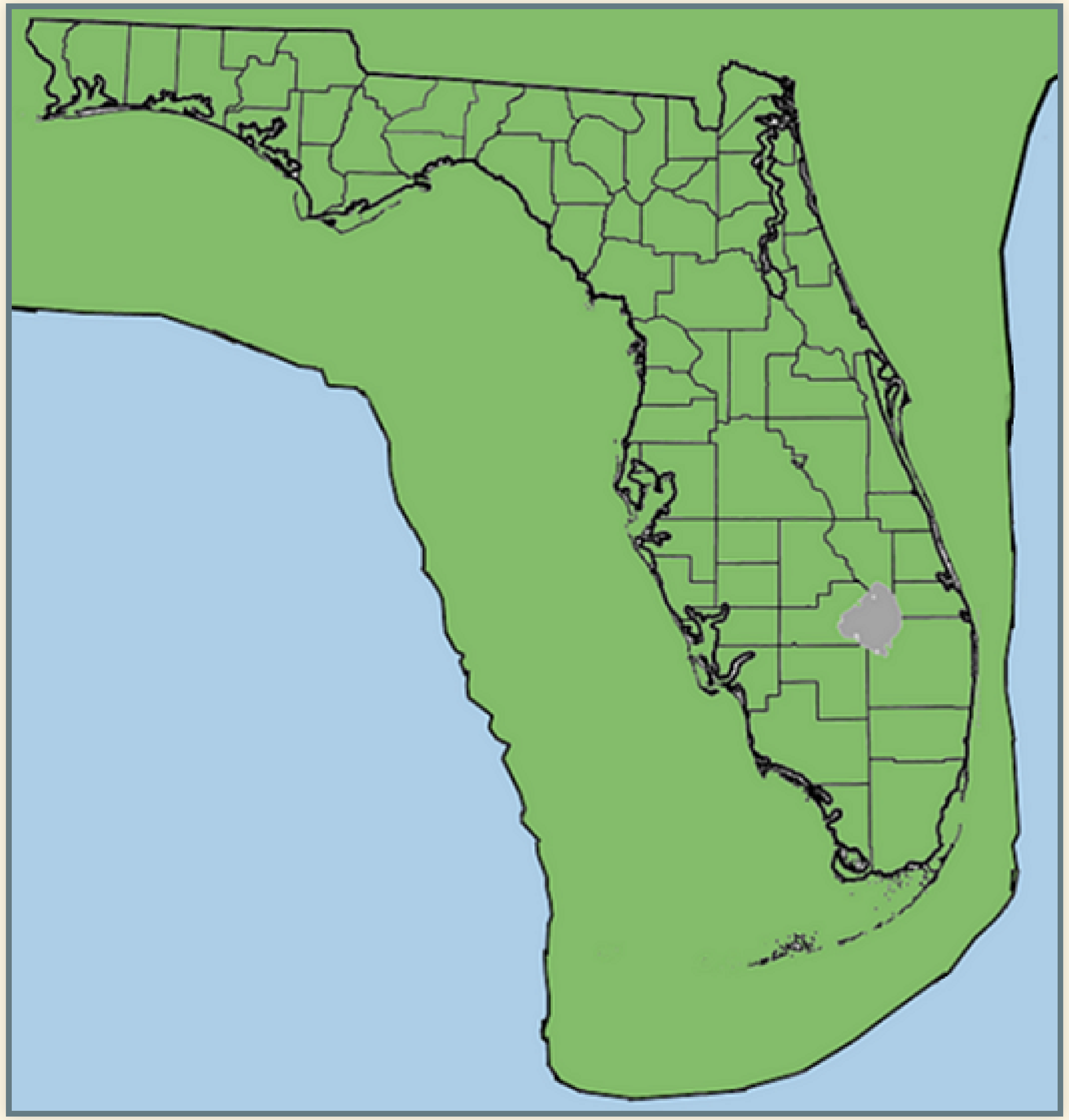
Sediment Climate Record



Florida Through History

Florida 10,000 years ago

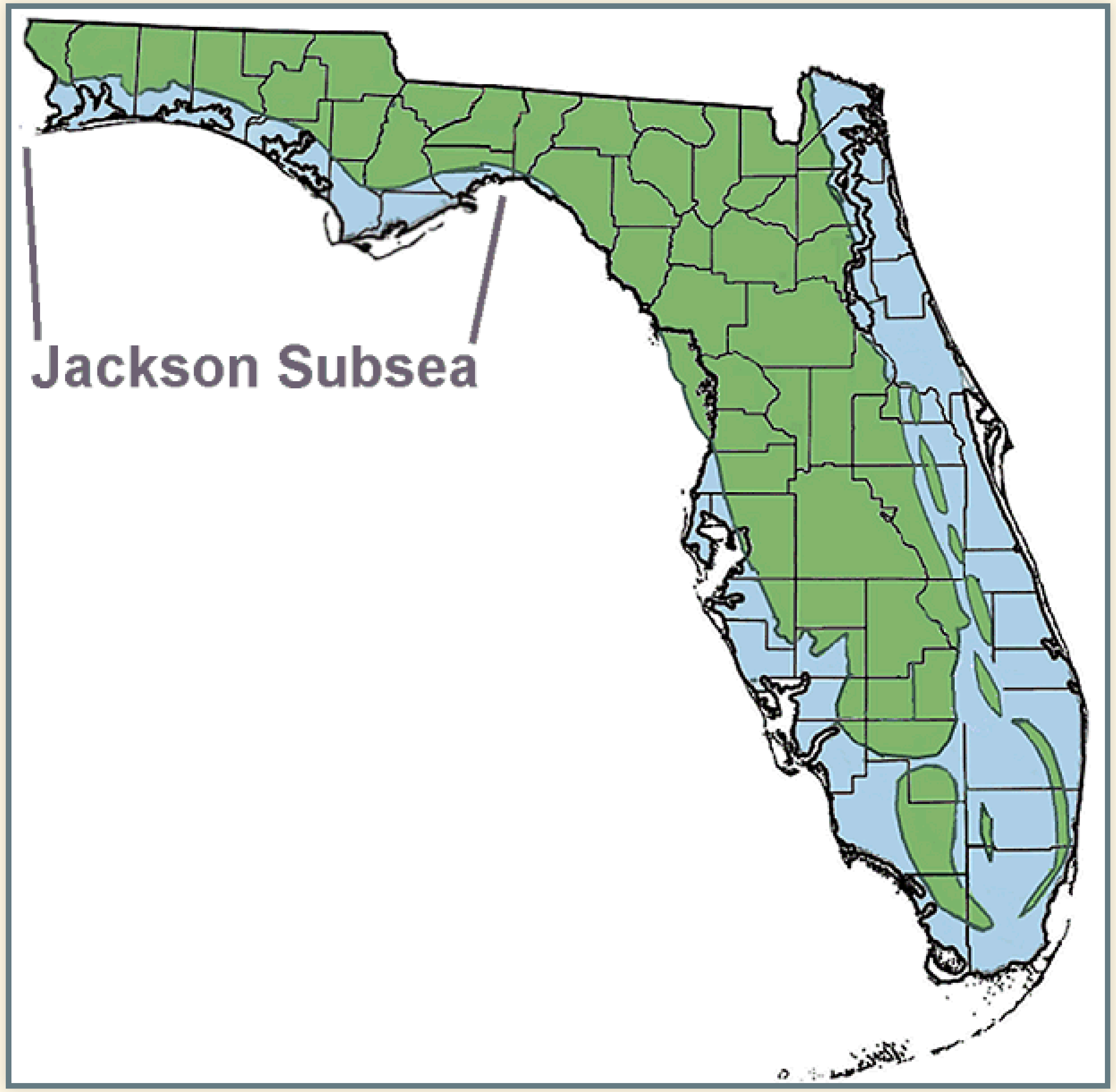
End of last ice age:
Sea level 400 feet lower



Florida 5 million years ago

Last time CO_2 was at today's levels.

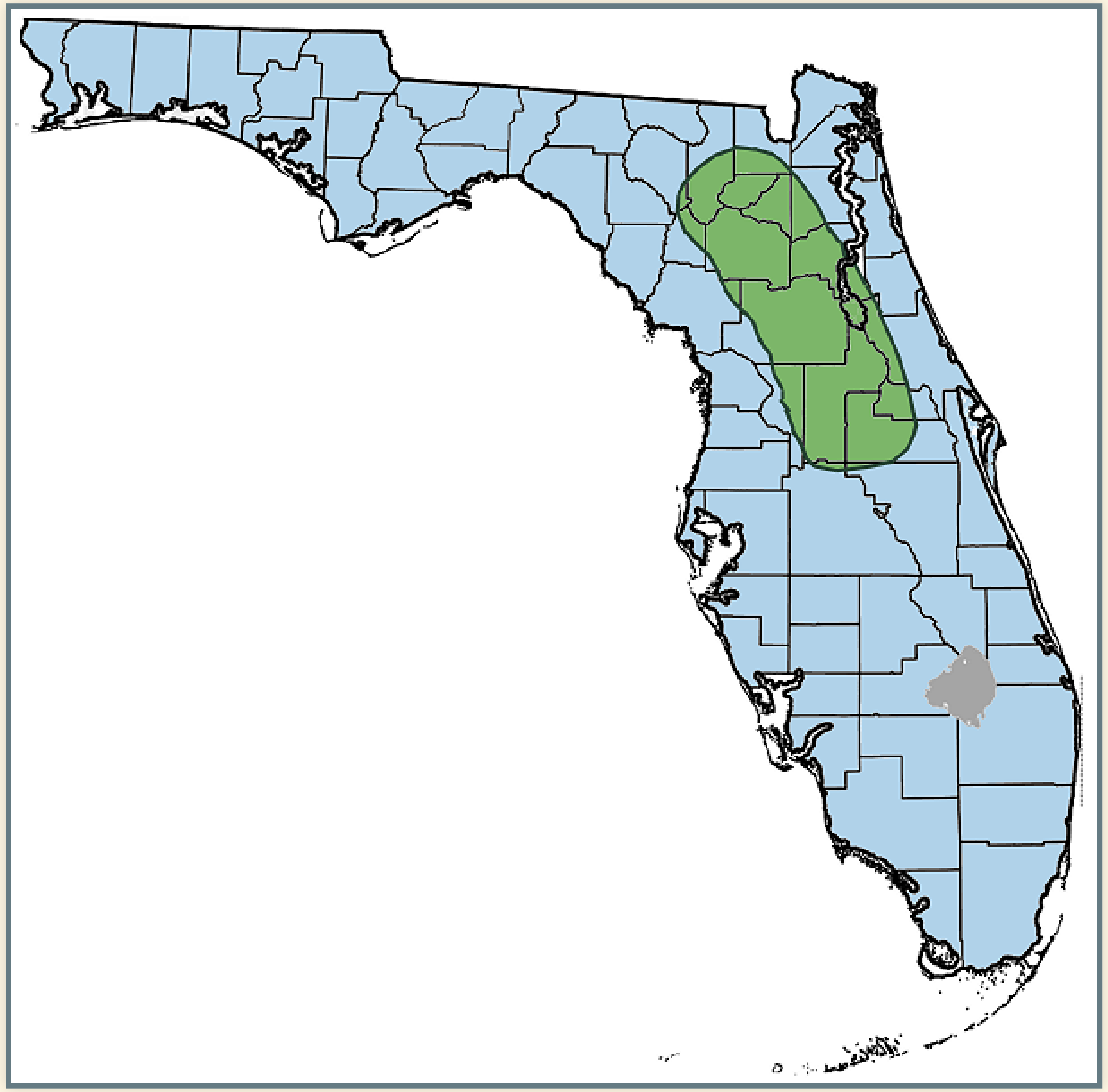
Sea level ~20 meters higher



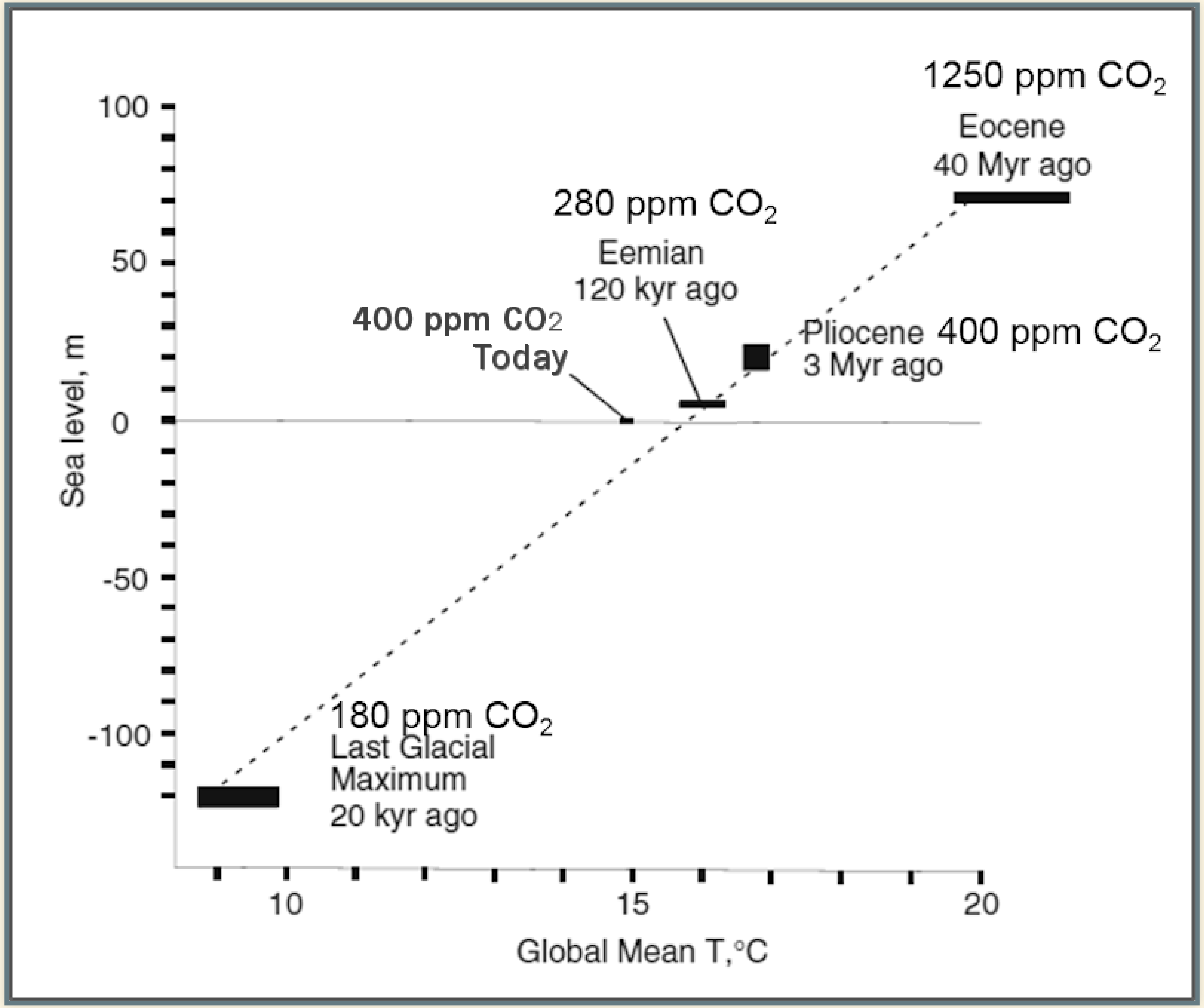
Florida 50 million years ago

CO_2 levels we might reach around 2100.

Sea level >70 meters higher



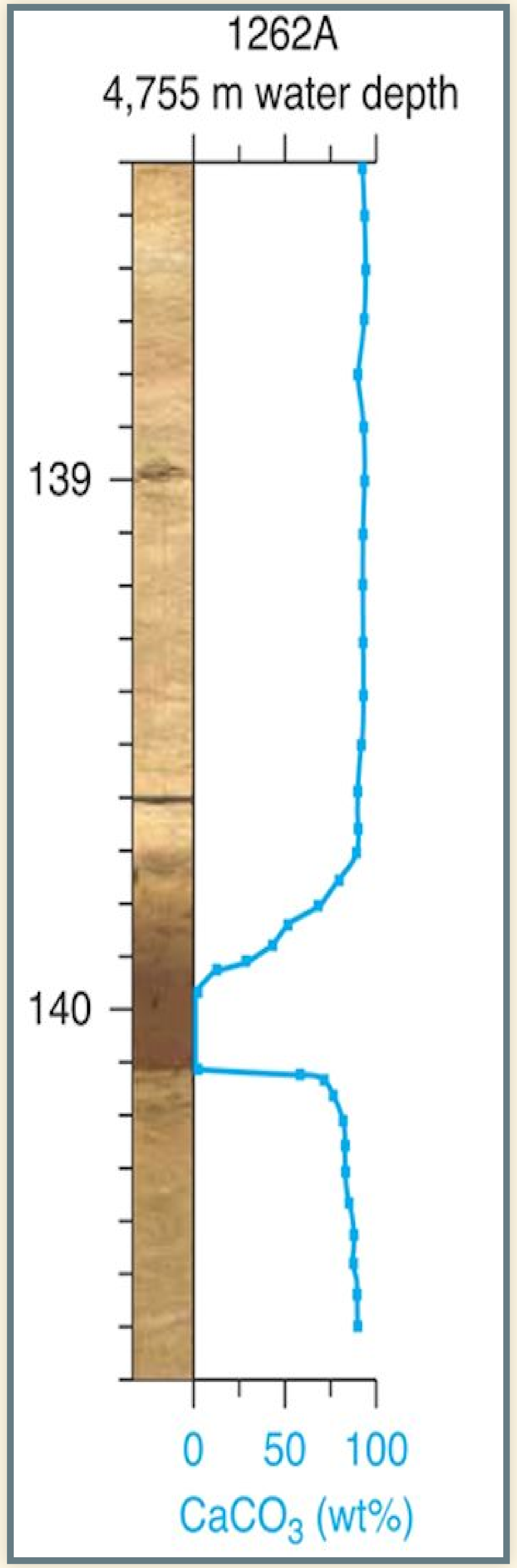
Summary of Past Sea Levels



Other Evidence of Past Climates …

Other Evidence of Past Climates …

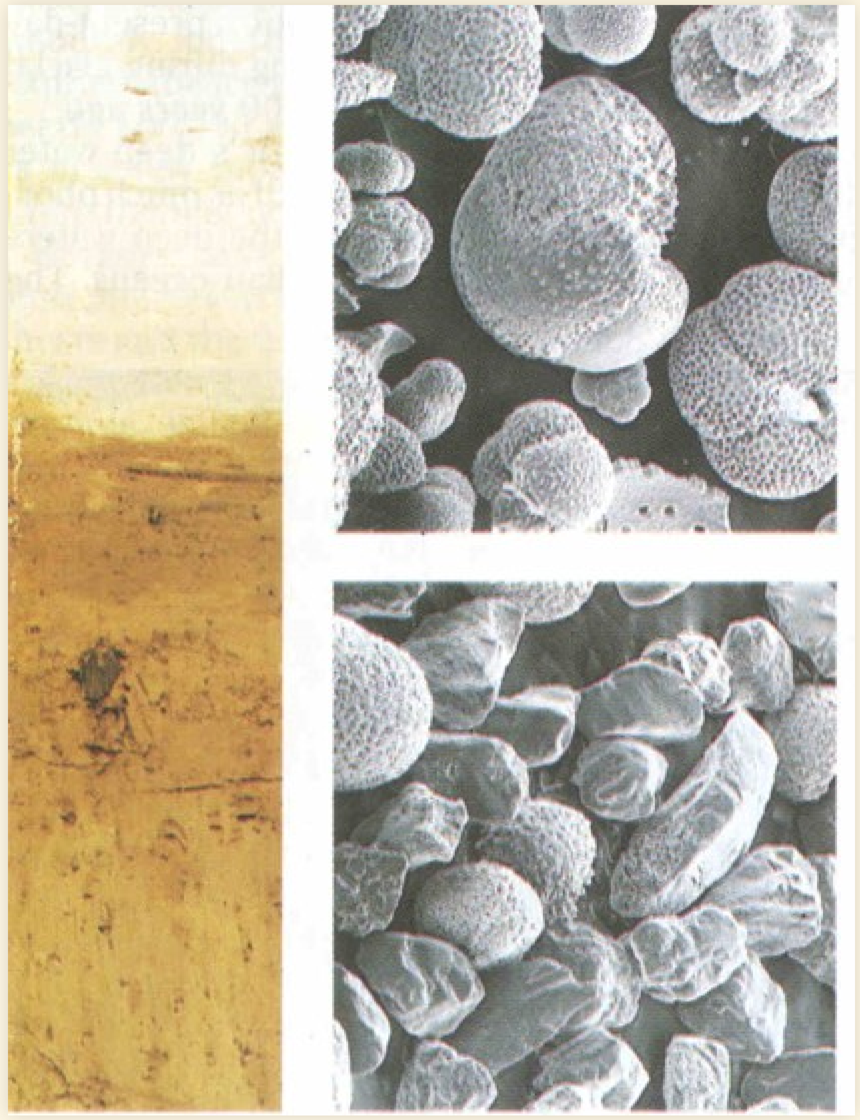
- Sediments tell us about history:
  - Bottom → top = oldest → youngest
- White carbonate sediments
- Red clay layer:
  - ~55 million years ago
  - Almost no carbonates
- What does red layer tell us?

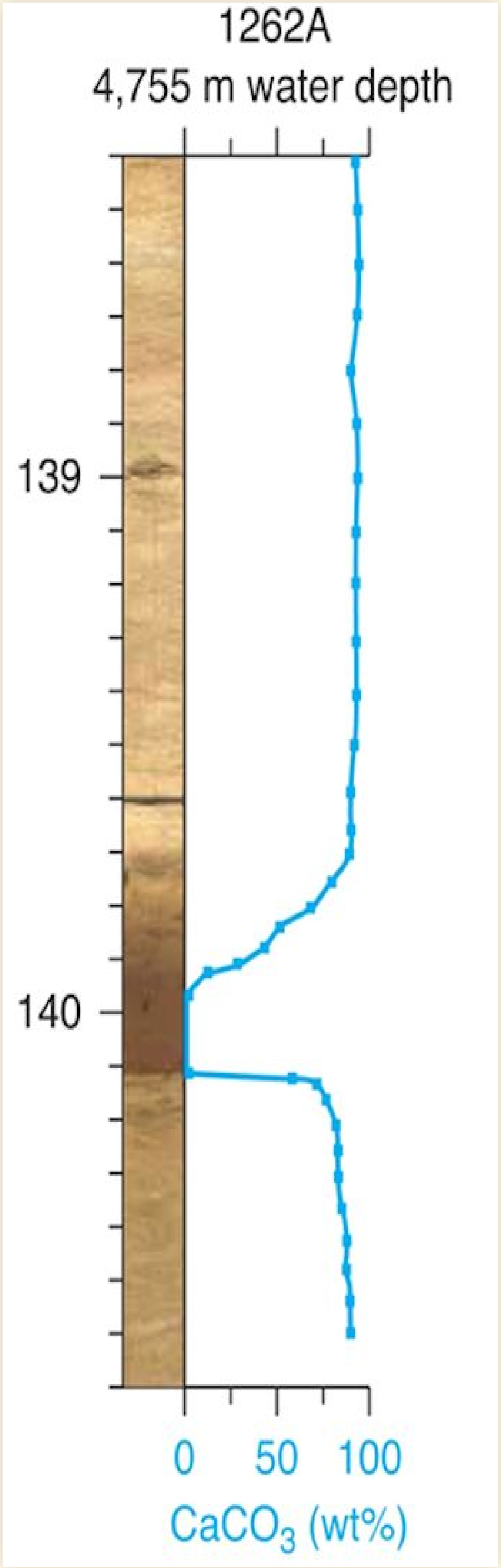


Other Evidence of Past Climates...

$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

- Alkaline Ocean:
  - High CO_3^{2-}: Reaction runs $\Leftarrow$
  - Carbonates survive on sea floor
- Acid Ocean:
  - Low CO_3^{2-}: Reaction runs $\Rightarrow$
  - Carbonates dissolve
  - Only clay is left
- Red clay layer $\Rightarrow$ ocean acidification
  - Large burst of CO_2 into atmosphere.

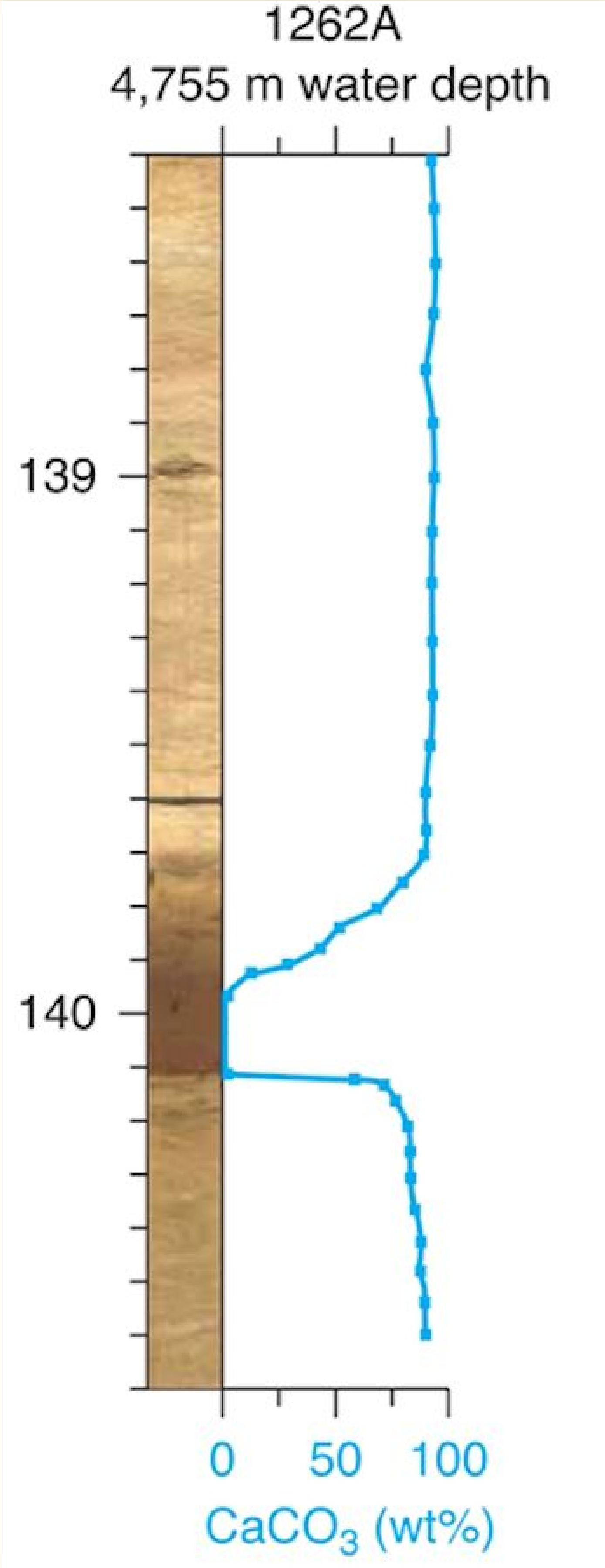




Other Evidence of Past Climates...

$$\mathrm{CaCO_3} \rightleftharpoons \mathrm{Ca^{2+}} + \mathrm{CO_3^{2-}}$$

- Just below red clay layer, $\delta^{13}C$ drops suddenly.
- What does that tell us?
- Lower ^{13}C means rise in CO_2 came from organic source.



Paleocene-Eocene Thermal Maximum

- 55 million years ago
- 1500–4500 GT carbon added to atmosphere in 1000 years
  - Compare:
    - 600 GT in atmosphere in 1700s,
    - 760 GT today
    - Known fossil fuels: ~5000 GT
- Temperature rose 5–9°C (9–16°F)
- Lasted ~120,000 years
  - Transition to cooler temperatures took ~40,000 years
- Eocene $\to \cdots \to$ Pliocene $\to$ Pleistocene
  - Gradual cooling for 50 million years
  - Permanent ice on Antarctica ~35 MYA
  - Permanent ice on Greenland, Alaska ~5 MYA
  - Ice age glaciation of North America, Europe begins ~2.8 MYA

Summary of Oxygen Isotopes

- Two different uses:
  - $\delta^{18}O$ in **glacial ice** tells us about **air temperature** near glacier
    - $\delta^{18}O$ is always negative,
      - but it can be more negative (lower) or less negative (higher).
      - Higher (less negative) $\delta^{18}O$ means warmer temperature.
  - $\delta^{18}O$ in **skeletons of deep-sea organisms** tells us about **sea level**
    - $\delta^{18}O$ is always positive.
    - Greater (more positive) $\delta^{18}O$ means lower sea-level.
  - Changes in ocean $\delta^{18}O$ are generally opposite to changes in glacial ice $\delta^{18}O$.
    - Growth of glaciers:
      - Transfers more light isotopes from ocean to ice.
      - More heavy isotopes left behind in oceans.